

## BUS BRIDGE INTERFACE SYSTEM

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TECHNICAL FIELD OF THE INVENTION

The technical field of this invention is micro-controllers, which are widely applied in complex computer systems having multiple busses. Multiple bus systems must provide bus controllers to allow for coherent and collision-free communication between the separate buses. Micro-controllers used for this purpose provide bus arbitration which determines, at a given time, which device has control of the bus in question. The present invention describes a crucial device element in the implementation of multiple bus micro-controllers, the bus bridge interface system.

BACKGROUND OF THE INVENTION

As computer systems have grown more complex, it has become common to employ multiple processors and a wide variety of peripheral devices to transfer data within a chip and from  
5 the chip to external devices and vice versa. Such systems almost always have a multiple set of busses separating, for convenience and performance reasons, the communication between similar devices. Multiple bus systems must provide bus controllers to allow for coherent and collision-free  
10 communication between separate buses. Micro-controllers are used for this purpose and they provide bus arbitration which determines, at a given time, which device has control of the bus in question.

A prominent standard bus system has emerged for high  
15 performance micro-controller designs. The Advanced Micro-controller Bus Architecture System AMBA has been defined by Advanced RISC Machines (ARM) Ltd. (Cambridge, U.K.) and is described in U.S. Patent 5,740,461, dated April 14, 1998. Computer systems of a CISC variety are complex instruction set  
20 computers and have total backward compatibility requirements over all versions. RISC (reduced instruction set computer) systems, by contrast, are designed to have simple instruction sets and maximized efficiency of operation. Complex operations are accomplished in RISC machines as well, but they are  
25 achieved by using combinations of simple instructions. The RISC machines of ARM Ltd. forming the AMBA architecture are of primary interest here.

The standard AMBA has two main busses, a high performance AHB bus and a peripheral bus APB of more moderate performance.  
30 The AHB bus is the main memory bus and contains RAM and an external memory controller. In this basic system definition,

if a high performance peripheral is required that will transfer large amounts of data, this peripheral is also placed on the high performance AHB bus. This decreases system performance, however, because the central processor unit (CPU) cannot have access to memory when the peripheral has control of the bus.

Advanced RISC Machines Ltd (ARM) has proposed an efficient arbitration scheme and split transfers to allow the CPU and the high performance peripheral to share bus time of the single AHB bus. ARM has also proposed use of a second bus for isolation and using a single arbiter. This proposal still allows only one transaction to progress at a given time period.

#### SUMMARY OF THE INVENTION

This invention describes an advanced high performance bus bridge, also known as AHB-to-HTB bus bridge. The AHB-to-HTB bus bridge of this invention provides a means for the interfacing of two separate AHB-style busses allowing communication between them and securing data integrity. Since these busses have different characteristics, one for CPU support and the other for support of a large amount of data transfer by a single peripheral, the bus bridge is defined with clear master-slave protocol.

The AHB-to-HTB bus bridge is a slave to the memory AHB bus and a master on the high performance data transfer bus, called the HTB bus. The HTB bus is also an AHB bus in timing and protocol. The AHB-to-HTB bus bridge contains all the slave AHB bus signals on the memory bus side but will generate the master AHB signals on the high performance data transfer bus side. The AHB-to-HTB bus bridge will also generate timing

to guarantee data integrity between the two AHB-style busses. When a memory bus master wishes to either read from or write data to the high performance data transfer bus, the AHB-to-HTB bus bridge creates timing conditions to prevent read-after-write (RAW) hazards and write-after-read (WAR) hazards due to potential delays induced in bus synchronization and arbitration.

#### BRIEF DESCRIPTION OF THE DRAWINGS

10        These and other aspects of this invention are illustrated in the drawings, in which:

Figure 1 illustrates the block diagram of a prior art advanced micro-controller bus architecture AMBA having a conventional AHB bus system;

15        Figure 2 illustrates the signal interconnections of a prior art single master, slave and arbiter combination in the AMBA architecture;

Figure 3 illustrates the block diagram of an enhanced advanced micro-controller bus architecture having the multiple transaction two AHB-style bus system of this invention with two arbitrators;

20        Figure 4 illustrates the interactions between AHB memory bus arbiter and HTB high performance data transfer bus arbiter functions; and

25        Figure 5 illustrates the AHB-to-HTB bus bridge block diagram.

#### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

30        The multiple transaction advanced high performance bus system (MTAHB) of this invention is used as an upgrade to the micro-controller bus architecture (AMBA) of Advanced RISC

Machines Ltd. (ARM). The AMBA machines use RISC processors which are identified by the name ARM processors. Advanced RISC Machines Ltd. (Cambridge, U.K.) has been awarded U.S. Patent 5,740,461, dated April 14, 1998 in which this class of  
5 machines is fully described. The techniques used in this invention are of wider applicability, as will be shown, and can be used in a variety of multi-processor systems having multiple bus architectures.

Figure 1 illustrates the AMBA standard. The AMBA has two  
10 main busses, an advanced high performance bus (AHB) 100 and an advanced peripheral bus (APB) 120 of more moderate performance. AHB bus 100 is the main memory bus and couples to CPU 101 via CPU advanced high performance memory bus interface 106 to random access memory (RAM) 107, read-only  
15 memory (ROM) 108 and an external memory interface (EMI) controller 102. Figure 1 further illustrates a second master device direct memory access (DMA) unit 103 also coupled to AHB bus 100. Arbitration for bus access between the two masters, CPU 101 and DMA 103, takes place in M-bus arbiter 110. M-bus  
20 arbiter 110 controls access to the various slave devices via M-bus decoder 111 and select lines 112. In this basic system definition, if a high performance peripheral is required that will transfer large amounts of data, this peripheral is also placed on the high performance AHB bus 100. Figure 1  
25 illustrates such a high performance peripheral device 130. Placing this high performance peripheral device 130 on AHB bus 100 decreases system performance, because CPU 101 and DMA 103 cannot have access to memory when high performance peripheral device 130 has control of AHB bus 100. ARM has proposed an  
30 efficient arbitration scheme and split transfers to allow the

CPU 101, DMA 103 and the high performance peripheral 130 to share bus time of the single AHB bus 100.

ARM has also proposed use of a second bus for isolation and using a single arbiter. As shown in Figure 1, this second  
5 bus is called the advanced peripheral bus (APB) 120. APB bus 120 operates in the same fashion as AHB bus 100. APB bus 120 is connected to AHB bus 100 via an AHB-to-APB bus bridge 109. AHB-to-APB bus bridge 109 is a slave to AHB bus 100. The two bus system with single M-bus arbiter 110 is of limited  
10 usefulness, because it allows only one transaction to progress at a given time period. Note that all high performance devices including memory and high performance peripheral device 130 are on AHB bus 100. All peripheral devices of moderate performance including UART 115, timer 116, keypad 117 as well  
15 as peripherals 121 to 123 reside on the peripheral bus 120.

Figure 2 illustrates the signal flow between a master requesting control of the AHB bus, the arbiter performing the arbitration decision and the slave selected by the master for a command to be executed in this standard AMBA system. AHB  
20 bust arbiter 111, AHB master 200 and AHB slave 210 each receive a reset signal HResetx 222 and a clock signal HClockx 223. The AHB master 200 makes the request of AHB arbiter 110 by activating HBusReqx signal 231. The AHB master 200 receives permission from AHB arbiter 110 by HGrantx signal 232. The  
25 AHB master 200 confirms the grant and locks this arbitration decision by HLock signal 233. AHB master 200 then sends address 205 to AHB decoder 111. AHB decoder 111 activates a select signal 112 supplied to the selected slave device. In this example the selected slave device is AHB slave 210. The  
30 interaction of AHB master 200 and AHB slave 210 is completed via the control signals 213 and acknowledged via HResp signal

211 and HReady signal 212. Data for read and write operations flows between all masters and all slaves via the AHB bus 100. AHB slave 210 supplies data to AHB bus 100 via HRData[31:0] bus 206 and receives data from AHB bus 100 via HWDData[31:0] bus 207. Likewise, AHB master 200 receives data from AHB bus 100 via HRData[31:0] bus 208 and supplies data to AHB bus 100 via HWDData[31:0] bus 209. Note in this regard that reads and writes are considered from the point of view of AHB master 200. Thus in a data read data flows from AHB slave 210 to AHB bus 100 via HRData[31:0] bus 206 and from AHB bus 100 via HRData[31:0] bus 208. Of course only one master is activated at a given time and this master selects only one slave on which it will execute a transfer (read or write) command.

Figure 3 illustrates the multiple transaction advanced high performance bus system (MTAHB) of this invention. The MTAHB uses two AHB-style buses: AHB bus 300 retained as a memory bus; and HTB bus 330 provided for high data transfer bus. AHB bus 300 has AHB bus arbiter/decoder 314 and HTB bus 330 has HTB bus arbiter/decoder 316. Communication between AHB bus 300 and HTB bus 330 takes place via AHB-to-HTB bus bridge 315. AHB-to-HTB bus bridge 315 provides more than just isolation between AHB bus 300 and HTB bus 330. AHB-to-HTB bus bridge 315 also allows for efficient communication between the two high performance busses. In this respect, MTAHB provides three main features:

1. a write buffer to reduce the number of stalls to the CPU 310 while writing to HTB bus 315;
2. a time-out counter allowing CPU 301 to change tasks if a read of HTB bus 330 takes too long; and
3. a set of control registers and control logic as required in bus-master devices.

The AHB bus 300 should contain as slaves only the blocks closely related to memory as well as AHB-to-APB bus bridge 309 to APB bus 320 and AHB-to-HTB bus bridge 315 to HTB bus 330. Note that APB bus 320 connects to moderate performance peripherals 321 to 322 in the same manner as illustrated in Figure 1. HTB bus 330 contains bus slave peripherals 331 and 332, bus master peripheral 333 and RAM 335. HTB bus 330 supports only two bus masters, high priority data transfer bus master peripheral 333 and AHB-to-HTB bus bridge 315. If more bus masters are required, another HTB bus can be added to the system through the use of another AHB-to-HTB bus bridge, connected as a slave on AHB bus 300.

Figure 4 illustrates the interactions between AHB bus arbiter 410 and HTB bus arbiter 421. When a device on the AHB bus 300, such as CPU 301 or DMA 303, wishes to communicate with a device on HTB bus 330 the following steps must occur. First, the device (CPU 301 or DMA 303) must win arbitration on the AHB bus 300. This is shown pictorially as a multiplexing operation where multiplexer 409 under control of AHB bus arbiter 410 selectively couples either CPU 301 or DMA 303 to AHB bus 300. In the actual implementation it is more common to tie attach three-state I/O interface stages from each device attached to the bus.

Next, AHB-to-HTB bus bridge 315 must win arbitration on the HTB bus 330. This is also shown as a multiplexing operation where multiplexer 420 under control of HTB arbiter 420 selectively couples either AHB-to-HTB bus bridge 315 or HTB bus master 333 to HTB bus 330. During this period when the arbitrations are pending, AHB-to-HTB bus bridge 315 must hold AHB bus 300 while waiting for HTB arbitration. This can seriously degrade system performance since no activity will be



occurring on AHB bus 300 during this period. AHB bus 300 will be the most active bus in most systems. To relieve this stall condition during a write condition, a write buffer is provided within AHB-to-HTB bus bridge 315.

5        Figure 5 illustrates the internal construction of AHB-to-HTB bus bridge 315. AHB-to-HTB bus bridge 315 includes FIFO control 501, bridge control logic 503 and AHB-HTB time-out counter 502 as shown. The full codings of control registers 540 (including CTRL register 541, STAT register 542 and CNTVAL register 543) are described below. Each of the control registers of control registers 540 are accessible by CPU 301. The write buffer is essentially a pair of FIFOs 510 and 520 with respective input register stages 509 and 519. Address FIFO 510 and data FIFO 520 have the same number of stages. 10        Figure 5 illustrates an example of 4 stages. Memory bus address latch 509 latches the full address from AHB bus 300. Memory bus data latch 519 latches the data from AHB bus 300. This differs from a traditional write buffer used in a cache scheme, where either the address or data is usually latched and then written back to the memory. The write buffer of this 15        inventions allows an AHB bus device to write data to the HTB bus device without having to wait for arbitration. So long as the write buffer is not full, AHB bus 300 will not stall due to waiting for arbitration on HTB bus 330. 20        If write buffer FIFOs 510 and 520 becomes full, bridge control logic 503 sets a WBFULL status bit within STAT register 542. If interrupt is enabled via a WBFULLE bit of CTRL register 541, then bridge control logic 503 generates an interrupt WBFULLI 561. If AHB bus 300 writes another word 25        when the write buffer FIFOs 510 and 520 are full, the previous word will be overwritten and lost. Under these conditions 30

bridge control logic 503 generates OVRUN interrupt 563 if overrun interrupts are enabled via a WBOI bit of STAT register 542. To prevent the loss of data, software of each writing device must make sure an overrun condition is not created.

- 5 When a full buffer becomes empty, bridge control logic 503 generates another interrupt WBEMTY 562 if a WBEMTYE bit of STAT register 542 enables such an interrupt.

In order to write to a HTB bus peripheral, CPU 301 or DMA 303 must first be granted control of AHB bus 300 by AHB bus  
10 arbiter 410. Then AHB-to-HTB bus bridge 315 must be granted control of HTB bus 330 by HTB bus arbiter 420. When the AHB-to-HTB bus bridge 315 is granted control of HTB bus 330, AHB-to-HTB bus bridge 315 will supply the address latched in address FIFO 510 to HTB bus decoder 421. HTB bus decoder 421  
15 will decode this address to supply the necessary chip select signals analogous to select signal 112 illustrated in Figures 1 and 2. Since the entire system contains only one memory map, this will not cause any conflicts to other devices on other busses. When generating this address on HTB bus 330,  
20 AHB-to-HTB bus bridge 315 will follow standard AHB bus timings, pipelining the address one cycle before outputting the data.

To prevent possible read-after-write (RAW) errors, if there is any data in write buffer FIFOs 510 and 520, AHB-to-  
25 HTB bus bridge 315 will not allow a read from HTB bus 330 until write buffer FIFOs 510 and 520 have cleared. If a read request is made, time-out counter 502 will start while write buffer FIFOs 510 and 520 are emptying data.

Referring again to Figure 5, when the first word is  
30 written to AHB-to-HTB bus bridge 315 from AHB bus 300, the full address will be latched into memory bus address latch 509

and data will be latched in memory bus data latch 519. When latched, the AHB-to-HTB bus bridge 315 will make a request HBusReqWrite 551 to the HTB Bus 330. A grant is acknowledged by grant signal HGrantx 553. If granted, the address in  
5 memory bus address latch 509 will be supplied to HAddr bus 511 and data in memory bus data latch 519 will be supplied to HData bus 521. This supply may be via write buffers FIFOs 510 and 520 if these FIFOs contain data. Arbiter interface 505 will also generate HLockx signal 546 to HTB arbiter 420. If  
10 not granted, the AHB-to-HTB bus bridge 315 can store more address and data in FIFOs 510 and 520 until these FIFOs are full. When the FIFOs 510 and 520 are full, AHB-to-HTB bus bridge 315 signals a not READY event 532 to the master on AHB bus 300.

15 Time-out counter 502 starts when AHB-to-HTB bus bridge 315 attempts to arbitrate to obtain control of HTB bus 330. The count of time-out counter 502 is initialized by the value stored in CNTVAL register 543. Time-out counter 502 is selectively enabled by the state of a TOE bit of CTRL register  
20 541. Upon time-out, bridge control logic sets a TOI bit of STAT register 542. Control registers 540 also generates a time-out interrupt 564 if time-out interrupts are enabled by a TOIE bit of CTRL register 541. Following such a time-out, when AHB-to-HTB bus bridge 315 is granted control of HTB bus  
25 330, bridge control logic 503 sets a RAI bit of status register 542. Additionally, AHB-to-HTB bus bridge 315 generates a read available interrupt (RAI) 565 AI interrupt is enabled by the RAIE bit of CTRL register 541.

The following is a summary of the content of the three  
30 control registers illustrated as block 540 of Figure 5 which

are a part of AHB-to-HTB bus bridge 315. The coding of control register CTRL 541 is listed in Table 1.

Bits	Mnemonic	Definition
15:7	Reserved	Reads undefined, writes no effect
6	WBFULLE	Write Buffer Full Interrupt Enable If Write Buffer Full 0 = no interrupt: 1 = will interrupt
5	WBEMTYE	Write Buffer Empty Interrupt Enable If Write Buffer Empty 0 = no interrupt: 1 = will interrupt
4	RAIE	Read Available Interrupt Enable If Read Available 0 = no interrupt: 1 = will interrupt
3	WBOIE	Write Buffer Over-run Interrupt Enable If Write Buffer Over-run 0 = no interrupt: 1 = will interrupt
2	WBE	Write Buffer Enable 0 = not enabled: 1 = enabled
1	TOIE	Time-Out Interrupt Enable If Time-Out Counter reaches 0x00 0 = no interrupt: 1 = will interrupt
0	TOE	Time-Out Enable 0 = not enabled: 1 = enabled

5

Table 1

Regarding the Write Buffer Enable bit (WBE), the size of the write buffer is determined upon manufacture. The example of Figure 5 includes a four stage write buffer. Regarding the time-out interrupt enable bit (TOIE), when the time-out counter 502 reaches 0x00, an interrupt is generated. If this

bit is set, the interrupt will be sent to CPU 301. Regarding the time-out enable bit (TOE), this selectively enables the time-out count-down register. This can be used to free CPU 301 to perform another task if AHB-to-HTB bus bridge 315 cannot win arbitration on HTB 330 bus in the time period of time-out counter 502.

The coding of status register STATUS 542 is listed in Table 2.

Bits	Mnemonic	Definition
15:6	Reserved	Reads undefined, writes no effect
5	WBFULL	Write Buffer Full 0 = not full: 1 = full
4	WBEMTY	Write Buffer Empty 0 = not empty: 1 = empty
3	RAI	Read Available Interrupt After a time-out event, AHB-to-HTB bus bridge has finally won arbitration 0 = Data may not be read from HTB bus 1 = Data may be read from HTB bus
2	WBOI	Write Buffer Overrun Interrupt 0 = Data not overwritten: 1 = Data overwritten
1	WBF	Write Buffer Full. 0 = not full: 1 = full
0	TOI	Time-Out Interrupt 0 = No Time-Out or not enabled 1 = Time-Out counter has reached 0

Table 2

Regarding the write buffer full bit (WBF), it is generally used to detect when the entire write buffer has been filled by writes to AHB-to-HTB bus bridge 315 and write buffer FIFOs 510 and 520 have not had a chance to write the data to HTB bus 330. This bit will become inactive as soon as a single location within write buffer FIFOs 510 and 520 is free. If write buffer FIFOs 510 and 520 are full and another write occurs, the previous data in the write buffer will be lost. Regarding the write buffer empty bit (WBEMPTY), this is active when the entire write buffer FIFOs 510 and 520 are empty. If write buffer FIFOs 510 and 520 had been full previously and then becomes empty, an interrupt is generated. Regarding the read available interrupt bit (RAI), this indicates that, after a time-out has occurred, that AHB-to-HTB bus bridge 315 has finally won arbitration and that the AHB bus device may proceed with a read. Regarding the write buffer overrun interrupt bit (WBOI), this indicates that the buffer was full and another write occurred, overwriting some data. This should not happen in normal operation. When write buffer FIFOs 510 and 520 are full, an HReady signal 532 on AHB bus 300 will be pulled high by AHB-to-HTB bus bridge 315 indicating no more transfers should occur. Regarding the write buffer full bit (WBF), this is a read-only status signal which indicates that write buffer FIFOs 510 and 520 are full and cannot accept new data. When active the write buffer full bit (WBF) also indicates that HReady signal 532 is active for AHB-to-HTB bus bridge 315. Regarding the time-out interrupt bit (TOI), this is active when time-out counter 502 reaches 0. This timer is provided so that during a read to HTB 330, if an unacceptable amount of time is required to win arbitration by

AHB-to-HTB bus bridge 315 on behalf of CPU 301, that CPU 301 may switch to another task and continue doing useful work.

The coding of counter value register CNTVAL 543 is listed in Table 3.

5

Bits	Mnemonic	Definition
15:0	CNTVAL	Start value for the Time-Out counter The number of HCLK cycles to time-out

Table 3

The counter value register CNTVAL 543 stores the start value for time-out counter 502. Upon expiration of the count of time-out counter 502, bridge control logic generates time-out interrupt 564 if the TOIE bit of CTRL register 541 enables such interrupts. Note that the TOE bit of CTRL register 541 controls whether time-out counter 503 is enabled or disabled.

This counter may be used during a read operation. If a peripheral already has won arbitration of HTB bus 330 and will not relinquish control due to a real-time constraint, the user may program a value here that will determine how many HCLK cycles to wait before causing a time-out interrupt. This time-out interrupt will permit CPU 301 on AHB bus 300 to stop waiting for a HTB bus grant and continue doing other operations such as running another task.

AHB-to-HTB bus bridge 315 further includes HTB bus data latch 529. HTB bus latch 529 latches data from read from HTB bus 330 via HRData bus 527 and supplies data to the AHB bus 300 via MRData bus 531. Note that AHB-to-HTB bus bridge 315 is a slave to AHB bus 300. Thus AHB-to-HTB bus bridge 315 cannot make a read or write request on AHB bus 300. Since

TI-30251

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AHB-to-HTB bus bridge 315 cannot make read or write requests, it cannot source an address to AHB bus 300. Accordingly, AHB-to-HTB bus bridge 315 does not need a HTB bus address latch.